SOIL SALINITY AND CARBONATE MINERALOGY

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The growing concern over the apparent increased salinization of soils within the prairie region of Canada and the U.S.A. is reflected in the many papers and workshops dealing with this subject over the last few years. In Saskatchewan, provincial and federal research and extension agencies have observed and described various situations where salinization appears to be increasing, and have attempted to document these increases and implement remedial action. While causes of salinization such as seepage or restricted drainage may appear obvious in some cases, there are many situations where a complete understanding of the salinization processes are not known due to the lack of information for the specific sites.

Ongoing studies dealing with the nature and genesis of secondary carbonates in soils suggest a possible tie-in between soil salinity and the nature of secondary calcites. Such a relationship may offer a means of evaluating the attendant conditions under which salinization occurs. This paper deals with the theoretical background and field evidence related to this relationship.

Background

In Western Canada, the carbonate minerals calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are components of most soil parent materials. During soil development these minerals undergo dissolution with the release of Ca^{++}, Mg^{++} and $CO_3^{=}$ ions to the soil solution. Upon being transported to lower depths (Fig. 1) much of the Ca^{++} is reprecipitated as calcite, leading to the build-up of secondary calcite in the Cca horizon just below the solum. Since the precipitation of dolomite does not occur under conditions prevailing at the earth's surface, the Mg^{++} remains in solution or in readily-soluble forms. If there is a Mg^{++} ion build-up in the soil solution, the secondary calcite will contain some Mg, the amount depending upon the ratio of Mg^{++}/Ca^{++} in the soil solution. This "partitioning effect" as described by Winland (1969) is governed by the following equation:

$$\left(\frac{Mg^{++}}{Ca^{++}}\right)_{calcite} = K_{Mg} \cdot \left(\frac{Mg^{++}}{Ca^{++}}\right)_{solution}$$

where K_{Mg} is the partitioning constant. The value for K_{Mg} is about 0.02 for calcites containing 0-20% $MgCO_3$. This indicates that only a small fraction of the total Mg is incorporated into calcite.

The amount of Mg included in secondary calcites can be readily detected by slow-scan X-ray diffraction analysis. As seen in Fig. 2, the pure minerals calcite and dolomite have distinct X-ray peaks at 3.03 Å and 2.88 Å, respectively. The presence of Mg-calcites causes a shift of the 3.03 Å peak to lower spacings (Ccag, Asquith), or a

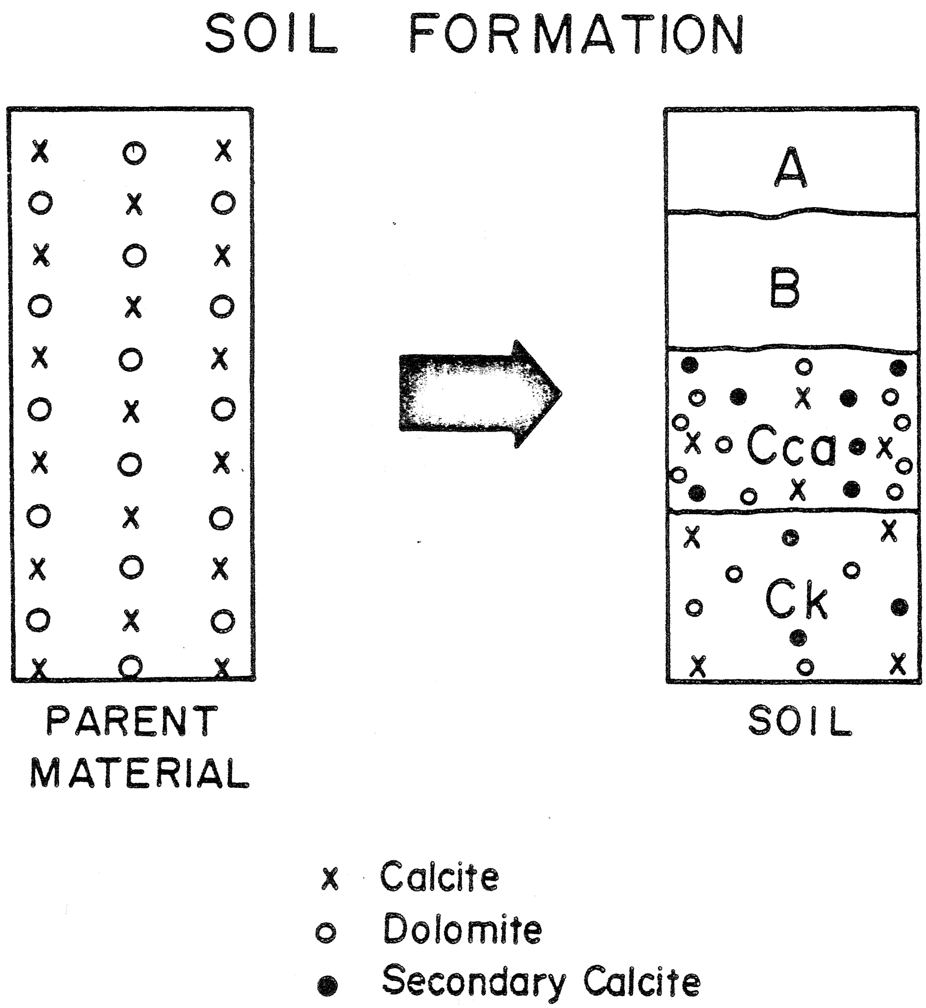

Figure 1. Schematic presentation of dissolution and reprecipitation of carbonate minerals during soil formation.

shift and broadening of the peak (Cca, Ryerson), or a marked skewing of the peak towards higher diffraction angles (Cca, Blaine Lake).

The definite identification of Mg-calcites in soils was first made by St. Arnaud and Herbillon in 1973. Their presence was noted in Solonetzic soils and in poorly drained saline depressions. Subsequent studies indicated that Mg-calcites also occur in Chernozemic and Luvisolic soils, invariably in situations where there has been a build-up of Mg^{++} (Mg^{++}/Ca^{++} ratio >1) in the soil solution within or in close proximity to Cca horizons. The secondary carbonates have been formed over a period of several thousands of years as evidenced by mean residence times of 1500-3000 years (unpublished data for Saskatchewan soils). It would thus seem logical that the presence of Mg-calcites should indicate not only a build-up of Mg^{++} in solution but also an

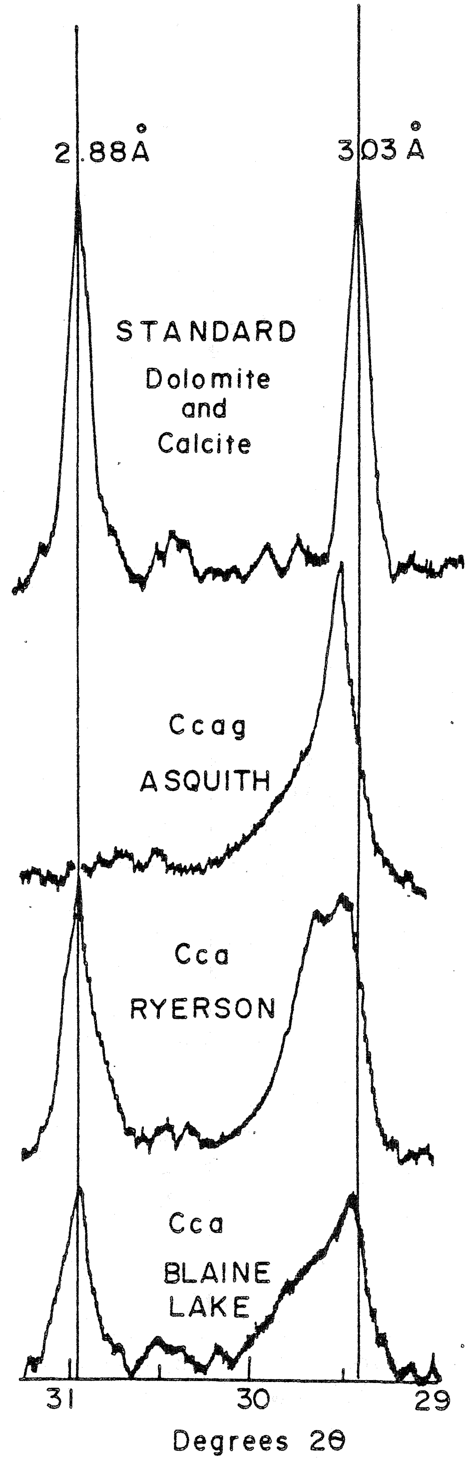

Figure 2. X-ray diffraction patterns of standard and soil carbonate minerals.

associated increase in total salinity. More significant still is the probability that the nature of the secondary carbonates can serve to indicate situations where salinity is of relatively recent occurrence.

The possible relationship between soil salinity and the nature of the secondary carbonates was investigated at three locations in central Saskatchewan. The Cutbank site was one previously studied by King (1976). The other two were salinity sites being studied by J. Peters, A.K. Ballantyne and W. Hurd, members of the Provincial Soil Salinity Program CO-ordinating Committee. All three sites occur within the Rosetown Map Sheet area. The soils occurring at the sites are described in the soil survey reports and maps for that area (Ellis et al., 1970).

The Cutbank Site (NW3-27-6-W3)

Soils of the area are mapped within the Weyburn Association. The soils are dominantly Chernozemic. The M4 topography (ridge and swale with limited external drainage) has slopes varying from 6% to 9%. Previous studies at the site (King, 1976) had served to establish soil variations as a function of landform parameters. Analyses of soils sampled along a transect (Fig. 3) were supplemented by deeper borings obtained later.

The salinity profile along the transect at the Cutbank site (Fig. 3) provides some insight into the salt distribution within a glacial till landscape. Such landscapes are of common occurrence across the prairie region of Western Canada. The following trends were observed:

1) The surface horizons have been leached free of soluble salts along the entire transect.
2) In upper and mid-slope positions, salinity increases with depth, reaching a maximum in the 2-4 meter zone and then decreases.
3) The depressions are deeply leached with no evidence of salts down to the 8-9 meter depth.
4) Carbonate accumulation horizons (Cca or carbonate-enriched Ck horizons) occur in both the upland and depressional soils.
5) Mg-calcites occur only in upper and mid-slope profiles where salt accumulations coincide with, or are within capillary reach of the Cca horizons. Soluble Mg^{++}/Ca^{++} ratios invariably exceed one in such horizons.
6) In the depressions, the secondary calcites are Mg-free, coincident with low (<1) soluble Mg^{++}/Ca^{++} ratios.

A significant feature of the salinity profile relates to the higher salt concentrations in the upslope positions and the lower concentrations in the depressional areas. This would suggest the lack of significant lateral moisture flow in soil areas such as this. While some lateral flow does occur (e.g. Soils #5, #11) it is probably less prevalent than usually expected. The distribution of soluble salts suggests that surface water and possibly snow accumulations in depressions are more important aspects of water redistribution in this

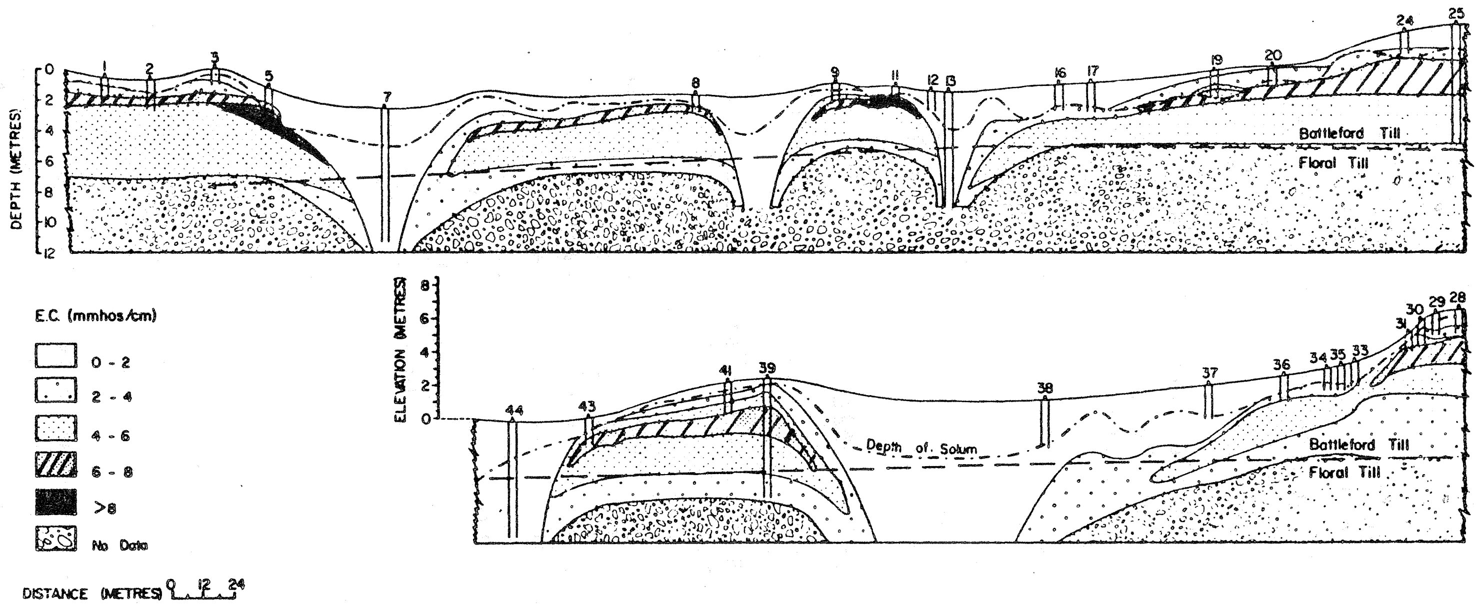

Figure 3. Salt distribution along a transect in a glacial till landscape (Cutbank Site).

landscape than is lateral movement within the soil itself. In depressional areas, waters from snowmelt and from surface run-off result in the removal of soluble salts, including Mg^{++}, to appreciable depths. In such locations, the secondary carbonates accumulate to a greater depth, so that Cca horizons are less pronounced and calcites are Mg-free. In upslope positions, the salt concentrations within the 2-4 meter depth are characterized by a high Mg^{++}/Ca^{++} ratio which is affecting the nature of the secondary calcites being precipitated. The absence of Mg-calcites in the depressional areas ties in with the low Mg^{++}/Ca^{++} ratios resulting from the pronounced leaching and removal of soluble Mg^{++}.

The contact of two tills, the Battleford and Floral has had no apparent effect on salt concentrations as seen from the salt-free depressions where salts are flushed well below the contact. The seemingly denser Floral till which occurs at a depth of 4 to 5 meters is apparently not affecting the flow of soil water in the depressions. In areas where the contact occurs at a shallower depth, the influence may be quite different. Current studies (Eilers and Acton, personal communication) are underway to establish the effect of shallower contacts between the Battleford and Floral till deposits.

Glenside Site (SW26-29-6-W3)

At this site, a shallow lacustrine deposit overlies glacial till. The soils in the vicinity are mapped within the Hanley (Solonetzic) and Weyburn (Chernozemic) Associations. The overall slope along the transect studied is about 6%.

The salinity profile (Fig. 4) clearly demonstrates that even though there is evidence of seepage of salts at the bottom of the slope, the glacial till deposit is highly saline along the complete transect. The profiles are Solonetzic in nature; the salinity is obviously an inherent characteristic of the deposit. The soil solution is typified by high soluble Mg^{++}/Ca^{++} ratios (>1) and the presence of Mg-calcites along the entire transect suggests that the high Mg^{++} levels have always been present or that the build-up has been continuous over the years. Any remedial measures at controlling evident seepage in such a landscape must take into account the fact that the salinity is a permanent feature of this type of landscape.

Birsay Site (SW4-25-8-W3)

At this site, a shallow lacustrine deposit overlies glacial till. The soils in the area are mapped within the Birsay Association. The soils are dominantly Chernozemic.

This site represents a textbook example of a saline seep due to the contact of two deposits, in this case a shallow lacustrine deposit over glacial till. There is an apparent flow of salts from higher to lower elevations along a 5-6% slope (Fig. 5). At location #3 on the upper slope, where the till occurs at the surface, the salt distribution with depth follows the same pattern as for the upslope soils developed on glacial till at the Cutbank site (Fig. 3). Presumably, the long-time

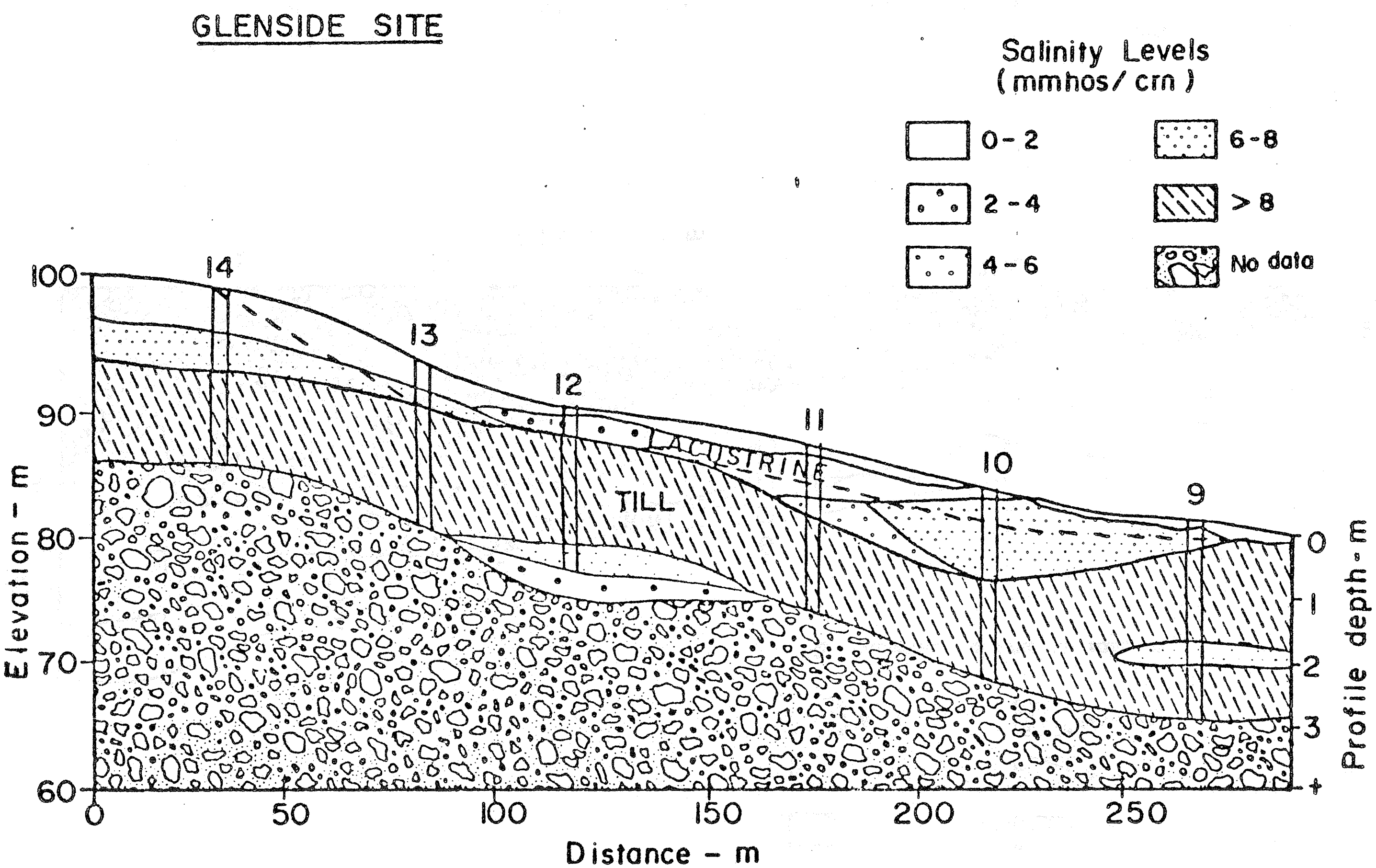

Figure 4. Salt distribution along a transect of a shallow lacustrine deposit over glacial till (Glenside Site). (The dotted line indicates the contact between the two deposits).

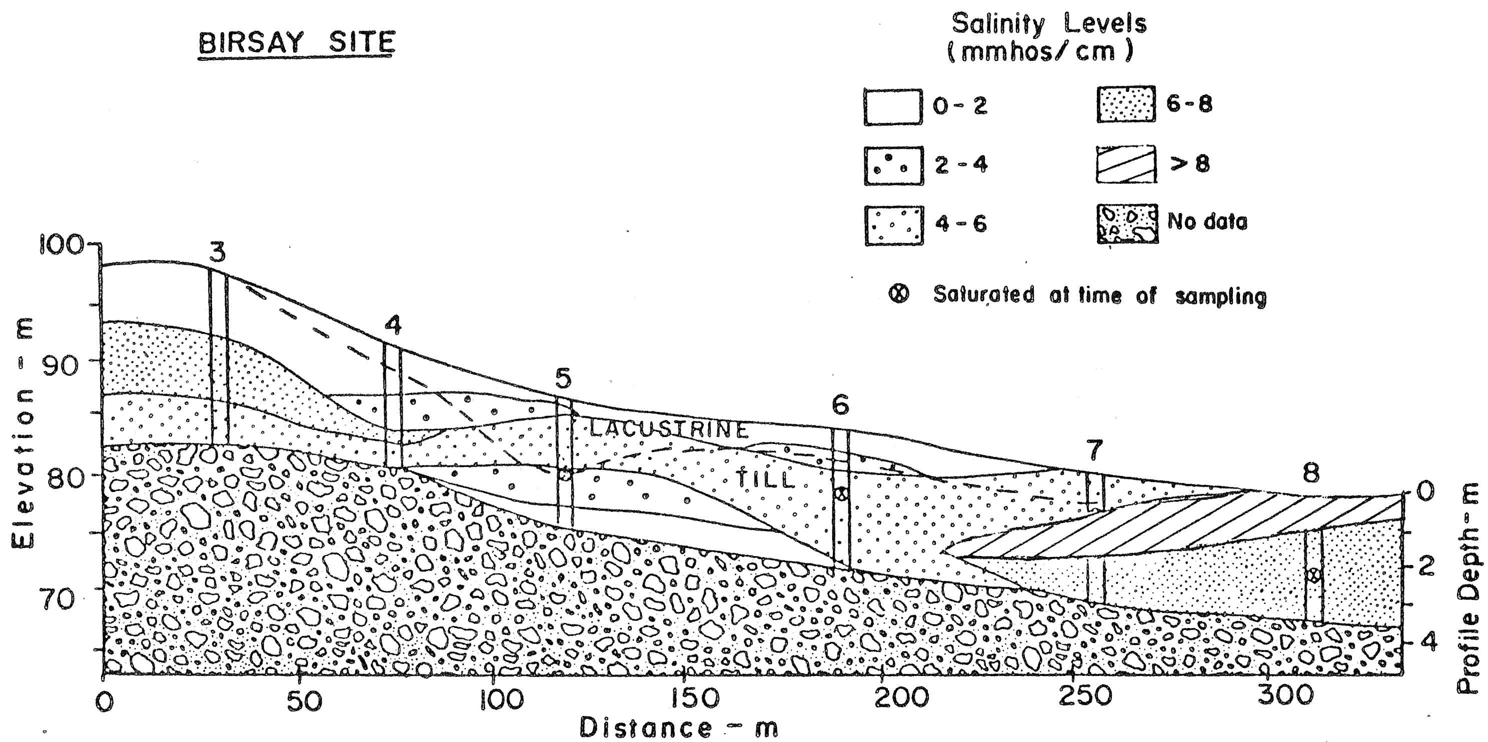

Figure 5. Salt distribution along a transect of a shallow lacustrine deposit over glacial till (Birsay Site). (The dotted line indicates the contact between the two deposits).

moisture penetration is sufficient to move salts downward to the 3-4 meter depth but not sufficient to result in the lateral movement of the salts. However, where the lacustrine deposit overlies the till, there is a different salt distribution with an increased concentration of salts down the slope. A surface accumulation of salts occurs at position #8 as a result of seepage at this point. Presumably the trapping of snow by a caragana hedge at location #5 and surface runoff from adjacent ridges have resulted in an accumulation of water at the contact of the lacustrine and till deposits.

Mg-calcites occur all along the transect, except at location #8. The presence of normal calcites at #8, despite a high salinity and soluble Mg^{++}/Ca^{++} ratios >1, confirms that the salinity is of relatively recent occurrence at this point in the landscape, and that if saline conditions did occur previously, they have never persisted. The cirque-like shape of the till surface (as established by detailed levels run at the site) and the water-saturated conditions which were observed at the contact at the time of sampling suggest that the build-up of water in the till depression lead to an over-flowing of the basin, resulting in the observed seep. Any measures taken to control the seepage at this site would have to be directed to preventing water accumulation upslope from the seep area.

Conclusions

While the initial thrust of this research was aimed at elucidating the nature and genesis of secondary carbonates in soils, the study and ensuing investigation have provided valuable information of relevance to soil studies in general and in particular to soil salinity and other field studies. The results clearly demonstrate the need to consider soils to depths significantly greater than is the present practice and also to consider them as parts of a continuum rather than as isolated bodies within a landscape. In the present study, it is apparent that the shallow borings which seldom reached the 2 meter depth would have failed to provide a meaningful landscape picture of salt and carbonate distributions with depth. The additional deeper borings to depths of 4 to 9 meters provided a much better understanding of the depth-concentration functions within the landscapes studied. In one instance, detailed elevation measurements were required to fully appreciate the effect of the contact between two deposits.

More specifically, the studies indicate that the nature of secondary carbonates may be a useful means of evaluating the persistence of existing soil solutions at any specific site. The presence of Mg-calcites is suggestive of a long-time build-up of Mg^{++} in soil solution. The presence of low soluble Mg^{++}/Ca^{++} ratios (<1) is indicative of good drainage to depth. In situations where the Mg^{++} level of the soil solution is high relative to Ca^{++} and the secondary calcites are Mg-free, the influx of Mg^{++} must have been relatively recent. The studies at three different field sites seem to confirm the theoretical aspects of the relationships proposed.

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